

# ESO for GOODS' sake

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**Abstract.** Currently public ESO data sets pertinent to the CDFS/GOODS field are briefly illustrated along with an indication on how to get access to them. Future ESO plans for complementing the GOODS database with optical/IR imaging and optical spectroscopy are also described.

## 1 Introduction

Recognizing the unique and long-lasting scientific value of the “SIRTF Legacy Programs”, the Director General of ESO issued an “Open Letter to the ESO Community” to ensure “adequate coverage from the observatories at La Silla and Paranal for all the approved Legacy Programs which have a substantial participation from the ESO community. ESO will ensure that appropriate allocation of time on relevant instruments, in line with the scientific goals of approved SIRTF Legacy programmes, is made in a timely manner. In the spirit of all the Legacy Programs, the resulting data will be immediately made public worldwide.” (see <http://www.eso.org/observing/misc/20000824.sirtf.html>). In this spirit, a team of ESO astronomers joined forces with the North American team led by Mark Dickinson at STScI, and the GOODS SIRTF Legacy Proposal was submitted in 2000, then complemented in 2001 by the HST/ACS Treasury Proposal led by Mauro Giavalisco. Both projects are now being implemented. The accompanying paper by Dickinson & Giavalisco describes the main scientific goals of the GOODS project, along with the planned observations with SIRTF and HST. This paper complements it with a description of the data being provided by ESO, and of the possibilities of spectroscopic follow up with the VLT. Involvement of the ESO community in the planning of the observations as well as in the reduction effort will be actively pursued.

## 2 Optical and Near-IR Imaging

There are several imaging data sets from observations taken at ESO telescopes that include the CDFS/GOODS field and are already publicly available. Some are part of the public ESO Imaging Survey (EIS), and some were obtained as part of “private” projects, but the data have become available after the one year proprietary period has expired. Other data have been obtained specifically for the GOODS project as a public survey (VLT Large Programme 68.A-0485, PI C. Cesarsky). Table 1 summarizes the situation as of February 2002. Fig. 1

shows the CDFS/GOODS field with superimposed the *brickwall* mosaic of the VLT/ISAAC observations currently under way. The raw and calibration *JHK* data having the planned integration time are already available for those bricks which identification number has the large format in Fig. 1. *JK* data for bricks 10, 11, 15 and 16 were secured by ESO programmes 64.O-0643, 66.A-0572 and 68.A-0544, whose PI (E. Giallongo) has kindly agreed to waive the residual proprietary time in such a way to have the reduced data being publicly released at the same time as the reduced GOODS data. For these bricks GOODS also provides the *H*-band data. The reduction of coadded, flux and astrometrically calibrated data is underway by the EIS Team, with the data release being planned for the end of March, 2002. The first public release of mosaiced images and source catalogs is planned for the end of July, 2002. ISAAC observations to complete the whole brickwall will continue in 2002 and 2003 as part of the GOODS VLT Large Programme. Real time information on the progress of the ESO/GOODS observations can be obtained from the URL <http://www.eso.org/science/goods/>, with links to the EIS and other databases.

While deep optical imaging was initially also envisaged with the VLT, this has become partly redundant after the approval of the GOODS/ACS Treasury Program, which will provide deep *BViz* imaging. Exception refers to deep *U*-band imaging with the VIMOS instrument and/or with a UV-optimized FORS-1 (if and when it becomes available). Depending on the public availability of data, additional VIMOS imaging may or may not be also needed for the selections of spectroscopic targets in the field surrounding the GOODS field (see Section 3.1).

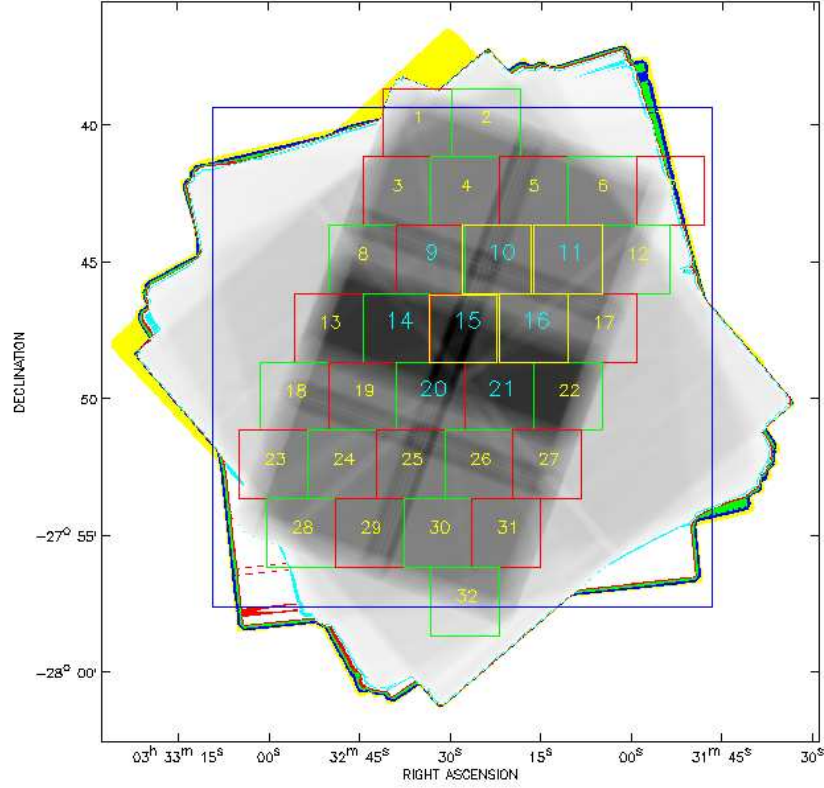
**Table 1.** ESO imaging data set on CDFS/GOODS (February 2002)

| Bands                  | Tel./Instrument | Area             | 5- $\sigma$ AB mag limits   | Programme |
|------------------------|-----------------|------------------|---|-----------|
| <i>UBVRI</i>           | 2.2m/WFI        | 30' $\times$ 30' | $U < 26.0$ , $B < 26.4$ , $V < 25.4$ ;<br>$R < 25.5$ ; $I < 24.7$ | EIS/DPS   |
| <i>JK<sub>s</sub></i>  | NTT/SOFI        | 20' $\times$ 20' | $J < 23.4$ ; $K_s < 22.6$   | EIS/DPS   |
| <i>RI</i>              | VLT/FORS        | 15' $\times$ 15' | $R < 27.0$ ; $I < 26.0$   | 64.O-0621 |
| <i>JHK<sub>s</sub></i> | VLT/ISAAC*      | 10' $\times$ 16' | $J < 25.3$ ; $H < 24.8$ ; $K_s < 24.4$                            | GOODS     |
| <i>BVR</i>             | 2.2m/WFI        | 30' $\times$ 30' | $B < 27.0$ ; $V < 26.5$ ; $R < 26.5$                              | GOODS     |

\* See text.

### 3 VLT Spectroscopy

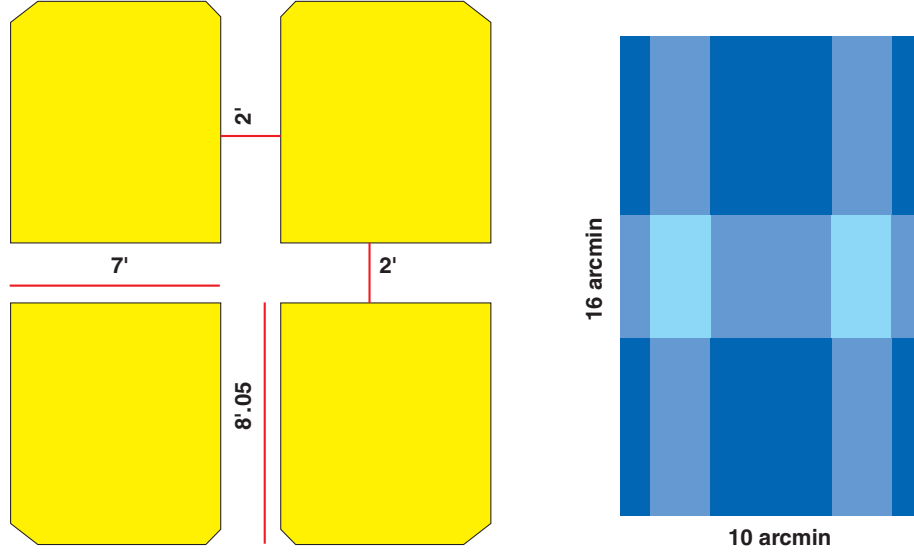
The most important ESO contribution to the GOODS project will certainly be the wide spectroscopic coverage of the field. No other Southern observatory has



**Fig. 1.** The ISAAC mosaic coverage of the CDFS/GOODS field (the shaded IRAC exposure map) is shown by the *brickwall* with individual pointings numbered from 1 to 32. Bricks with a large-size identification number have already been completed. The Chandra coverage is shown by the set of shaded squares with various orientations. The centered, unshaded square shows the EIS/DPS Deep-2c field as covered by SOFI.

high-multiplex spectroscopic capabilities comparable to those of the VLT. As of February 2002, more than 30 nights of multi-object spectroscopy have already been allocated at VLT/FORS1-2 for several scientific programs (e.g. the  $K < 20$  redshift survey; identification of Chandra sources; study of high- $z$  dropouts). To date, several hundred redshifts have been measured in the CDF-S area. This increasing spectroscopic data set amassed with the VLT is already public in the ESO Science Archive or will become public before the SIRTf data are taken.

However, these data either cover only a small fraction of the GOODS field, or only very specific types of targets, such as e.g. X-ray sources or a few Lyman-



**Fig. 2.** *Left:* the geometry of the VIMOS field of view, for either imaging or multiobject spectroscopy. *Right:* the CDFS/GOODS  $10' \times 16'$  field, in the same scale as the VIMOS FoV (left). The VIMOS imprinting on the GOODS field is rendered with different shadings. Dark areas: areas common to all 4 default VIMOS pointings (A set of subfields). Shaded areas: areas common to 2 default VIMOS pointings (B set of subfields). Lightly shaded areas: areas covered by only one VIMOS pointing (C set of subfields).

**Table 2.** Cumulative Source Counts in the CDFS Field

| $M_{AB}$ | $N_R^{EIS}$ | $N_I^{EIS}$ | $N_R^{GOODS}$ | $N_I^{GOODS}$ |
|----------|-------------|-------------|---------------|---------------|
| 22       | 3628        | 5794        | 600           | 1000          |
| 23       | 8009        | 11096       | 1300          | 2000          |
| 24       | 17962       | 20755       | 3000          | 3500          |
| 25       | 35949       | 31148*      | 6000          | 5500*         |
| 26       | 52840*      |             | 9400*         |               |

\* Incomplete counts in these magnitude bins.

break galaxies. Table 2 gives the cumulative source number counts in the  $R$  and  $I$  bands (columns 2 and 3, respectively) as derived from the EIS/DPS data for the Deep-2c field that includes the CDFS/GOODS field (Arnouts et al. 2002, A&A, 379, 740). Scaling by the areas, columns 4 and 5 give the number of sources within the GOODS field.

It appears from Table 2 that no more than  $\sim 6000$  objects in the GOODS field are bright enough (i.e. down to  $R_{AB}$  or  $I_{AB} = 25$ ) for a low-resolution spectrum

to be useful, e.g. to provide the redshift. Hence, the multiplex capabilities of the VLT instruments ensure the possibility to observe them all in a quite reasonable amount of telescope time. This is now explored in more quantitative terms.

### 3.1 VIMOS Spectroscopy

The layout of the VIMOS FoV is shown in Fig. 2 (left panel). A minimum of 4 VIMOS pointings is necessary to cover the whole GOODS field. A default pattern may consist of 4 VIMOS pointings in which in turn each of the 4 outer corners of the VIMOS FoV coincides with each of the 4 GOODS field corners, with the long (dispersion) axis of VIMOS parallel to the long side of GOODS. The missing triangles at the VIMOS corners are ignored.

For each pointing, the central cross gaps of VIMOS separate 4 sub-fields over GOODS, for a total coverage of  $112 \text{ arcmin}^2$ . Hence, for each pointing, a fraction  $112/160$  (70%) of the GOODS field is accessible to spectroscopy. The fraction of the VIMOS multiplex expendable on GOODS is  $112/224$  (50%), i.e., with an *effective multiplex*  $0.5 \times 800 = 400$  (in low resolution mode).

Moreover, the 4 default pointings of VIMOS imprint on the GOODS field a set of subfields, with some being common to all 4 pointings, some only to 2 pointings, and 2 subfields are covered by only one pointing. One defines these 3 sets of subfields as set A, B and C, respectively. The area of set A and B is  $72 \text{ arcmin}^2$  each (45% of GOODS each) while set C has an area of  $16 \text{ arcmin}^2$  (10% of GOODS). The default (A,B,C) pattern imprinted on the GOODS field is shown in Fig. 2 (right panel).

The surface density of targets ( $6000/160=37.5 \text{ arcmin}^{-2}$ ) is  $\sim 10$  times larger than the surface density of VIMOS slits ( $800/224=3.6 \text{ arcmin}^{-2}$ ). Hence, if one insists on having completeness in set C one needs at least 10 pointings to cover this small (10%) part of the GOODS field, while automatically set B and A would be observed two times and four times more than strictly needed to ensure completeness, respectively.

In a more time-saving approach, one may ensure completeness in set B, which requires this set to be covered by at least 12 pointings. Automatically, set C will be covered by 6 pointings (60% completeness), and set A by 24 pointings (twice more than strictly needed to ensure completeness). Hence, after having achieved completeness in set A, the 12 additional pointings will allow the observation of a subset of the targets in this field for longer integration times. In the limit, some targets could be observed for up to  $\sim 13$  times the basic exposure time. In this scheme, 24 pointings are required and assuming 4 hours integration time per pointing this makes a total of  $24 \times 4=96$  hours of integration, plus 20% overhead makes  $\sim 120$  hours, or  $\sim 13$  nights. These 13 nights will ensure that  $\sim 96\%$  of the targets are observed at least once with 4 hours integration, while 45% of the targets (those in set A) could be observed with an integration of 8 hours each, or a smaller fraction with even longer integrations.

This somewhat laborious exercise demonstrates that the geometries of the GOODS field and the VIMOS FoV combine in such a way that, when ensuring

the complete spectroscopic coverage of the field, one has automatically the opportunity to integrate on some of the targets for longer times than others. For this to be achieved some targets will have to be kept in more than one VIMOS multislit mask.

Very simple color criteria can be adopted to assign targets to either observations with the red or the blue low-resolution grism of VIMOS, in such a way to maximize the chance to obtain a high S/N spectrum. Similarly, just a magnitude limit criterion can be adopted for the selection of targets to be observed for multiples of the basic exposure time. Finally, having only 50% of the VIMOS spectroscopic multiplex used on the GOODS field, the other 50% will be available to get spectra of objects in the accessible area around GOODS. This should allow to get spectra of nearly as many objects outside GOODS as inside it, i.e. 6000 objects.

### 3.2 FORS2 Spectroscopy

While having a smaller FoV and lower multiplex compared to VIMOS, FORS2 offers an attractive complementary capability. Its throughput is about twice that of VIMOS longward of  $\sim 800$  nm, with the additional advantage of providing virtually fringe-free CCD frames. On red objects, FORS2 may go  $\sim 1$  mag or more deeper than VIMOS, or could reach much better S/N, given also the higher resolution ( $\times 3$ ) that should help resolve the OH lines. For multiobject spectroscopy, the effective FoV of FORS2 is  $\sim 6.8 \times 3.2 \simeq 22$  arcmin<sup>2</sup> and 9 pointings are sufficient to cover the whole GOODS field, with minimal overlap between pointings. With a multiplex  $\sim 40$ , such 9 pointings enables  $\sim 360$  objects to be observed, selected according to a simple color criterion. 18 masks exposed for 4 hours each would permit observations of  $> 500$  faint, red objects, with galaxies in faintest magnitude bin observed on two masks for a total of 8 hours. The integration time for the faintest objects would be longer than for typical VIMOS exposures, ensuring that features will be recognizable in spectra with no emission lines. This FORS2 program would require  $9 \times 2 \times 4 \times 1.2 = 86$  hours of telescope time including overhead, or  $\sim 10$  nights.

## 4 Conclusions

ESO is committed to provide its best possible contribution to the scientific effort started with the GOODS SIRTf Legacy and HST/ACS Treasury projects. This will include complementary optical and near-IR imaging, while a proposal will be submitted to the ESO Observational Programme Committee aimed to provide the whole astronomical community with the complete spectroscopic coverage of the CDFS/GOODS field. This proposal will follow the lines sketched in this paper, and should result in a complete, homogeneous database obtained with the minimum possible VLT time. Together with the complementary data from space, the ESO contribution is meant to establish a unique, long-lasting set of tools for the study of galaxy formation and evolution, hence preparing the way for further advances in the next decade with ALMA and NGST.